SCATTERING FROM THE QUASI-OPTICAL FERRITE CIRCULATOR USING A COUPLED INTEGRAL EQUATION/FEM SOLUTION†

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I. Introduction

Ferrite materials are used in microwave devices that exploit the property of Faraday rotation to give non-reciprocal behavior. Examples of common waveguide components that use ferrite materials include circulators, isolators and gyrators. These waveguide devices are difficult to design in the millimeter range due to the tighter tolerances required, increasing loss at higher frequencies, and heat dissipation problems. Therefore suitable replacements that operate in the millimeter range have been developed[1-3] that are quasi-optical in operation, requiring no confining waveguide. Such operation is especially desirable to avoid arcing at high power levels since cross-sectional waveguide area decreases as frequency increases.

Transmitters of the JPL/NASA Deep Space Network(DSN) typically operate at power levels in excess of 100 kW. This causes heat dissipation and loss problems even in the conventional DSN transmit frequencies of S and X band. These problems are compounded by operation in continuous mode, rather than in pulsed operation where the average power is low. In an effort to avoid the heat dissipation, waveguide loss, and arcing problems aggravated by high average power, the DSN has helped pioneer the development of Beam Waveguide antennas. These Beam Waveguide antennas use quasi-optical techniques to confine the fields, eliminating waveguide usage and their associated losses.

11. The Ferrite Circulator

The development of quasi-optical, non-reciprocal devices is natural to the Beam Waveguide environment. In particular, the practical use of a ferrite circulator for low power has already been demonstrated[4]. In this work Fitzgerald[4] suggested that design of such a device may be capable of handling powers in excess of 350 kW. Fig, 1 shows the I in ferrite circulator that will be considered here.

There are several issues that affect the choice of a proper ferrite material for possible high power applications, The loss tangent of suitable materials is generally low, with loss tangents ≤ 0.0002 available. If the ferrite is operated in the below resonance condition, it can be shown that the Faraday rotation through such a device is essentially independent of frequency and proportional to the saturation

†The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

magnetization, $4\pi M_s$[1]. Since the thermal Conductivity y oft ypical ferrite materials is low, it is desirable for the required Faraday rotation of a plane wave through the disk to occur in a minimum distance. This helps minimize the length of the thermal path. Since the saturation magnetization is a function of temperature this also helps stabilize the rotation. So a main issue for a quasi-optical ferrite circulator, if properl y designed, can become onc of heat rejection and temperature stabilization.

111. Anisotropic Finite Element Method Solution

In order to address the above issues, a detailed analysis of the ferrite circulator is needed. In the past this has been done be considering a ferrite medium of infinite extent [1 -3]. The symmetric FEM/MOM formulation was extended for the anisotropic ferrite media case[5]. Validation required comparison to an analytical solution to the ferrite filled cavity resonator. Comparison of these two methods showed agreement to less than O. 15% for the first seven modes of the ferrite cavity, Spurious modes were not found with this formulation.

With the an isotropic media validated from the ferrite filled cavity, the method was then applied to the ferrite quasi-optical circulator problem. This problem consists of a magnetized ferrite cylinder matched on both sides with quarter-wave slabs of quartz depicted in Fig. 1. Results for the bistatic RCS for phi polarized plane wave incident on the unmagnetized disk where $\mu_r = 1$ and $\varepsilon_r = 14.8$ is demonstrated in Figs. 2. and 3. Fig. 4 shows the theta polarized component of the RCS due to the same phi polarized incident plane wave that is not present in the unmagnetized case.

To properly illuminate the ferrite disk in the quasi-optical environment of the Beam Waveguide, the use of Gaussian beam excitation has also been investigated. This allows the scattering from the disk to be simulated at a beam waist as it would be used in practice. Potential arcing problems, areas subject to higher electric fields, and areas of high loss can be identified.

IV. References

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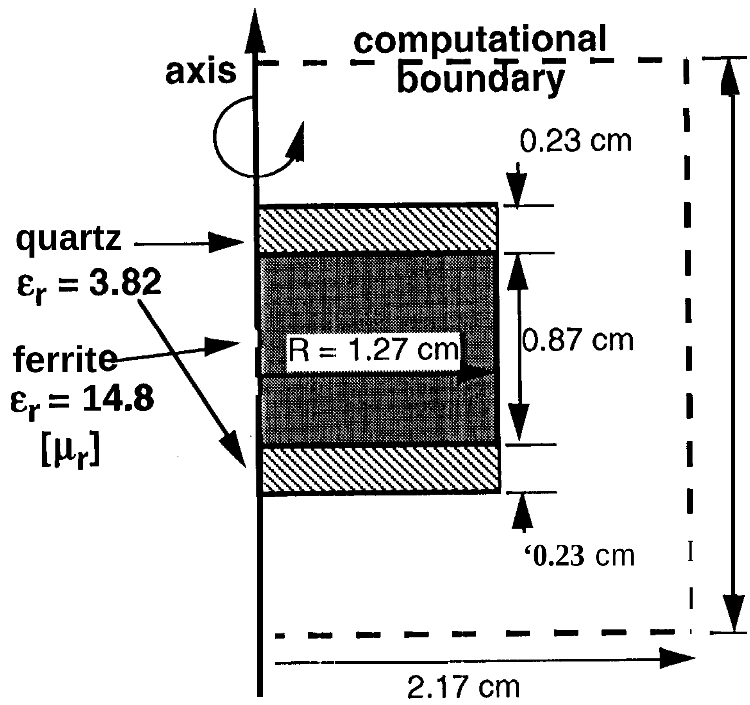

Fig. 1. Geometry of the ferrite circulator

Fig. 2. Bistatic RCS of dielectric cylinder(ε_r = 14.8) with quartz(ε_r = 3.82) matching layers, f = 17.0 GHz

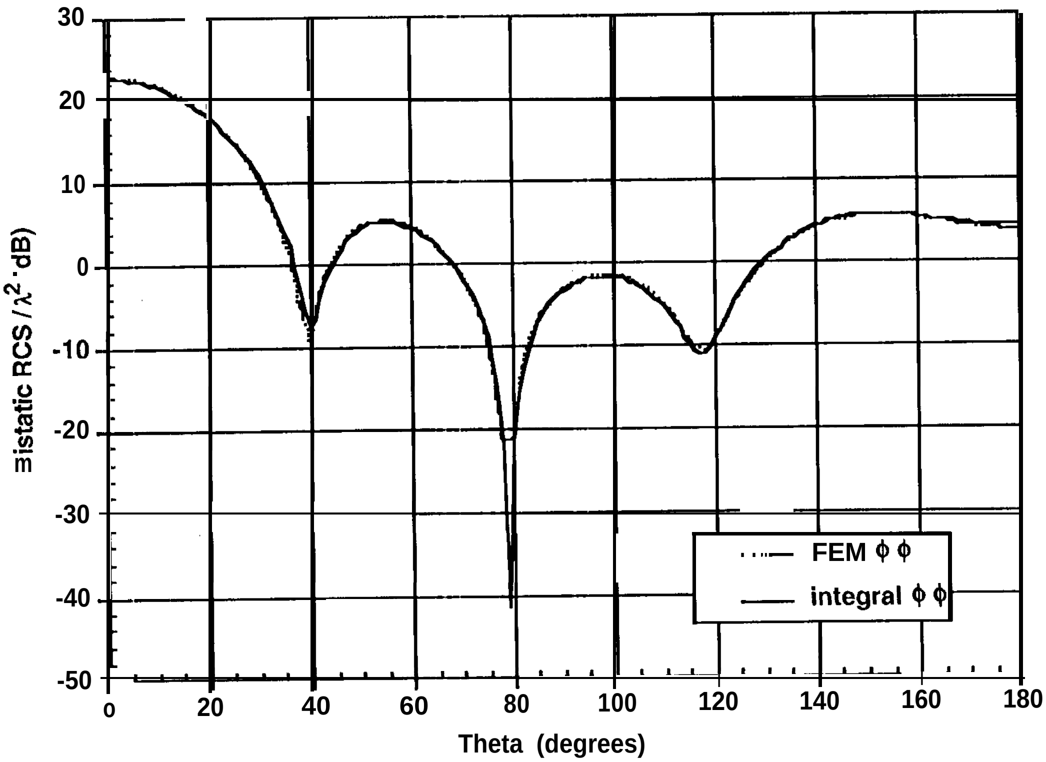

Fig. 3. Bistatic RCS of dielectric cylinder(ε_r = 14.8) with quartz(ε_r = 3.82) matching layers, f = 17.0 GHz

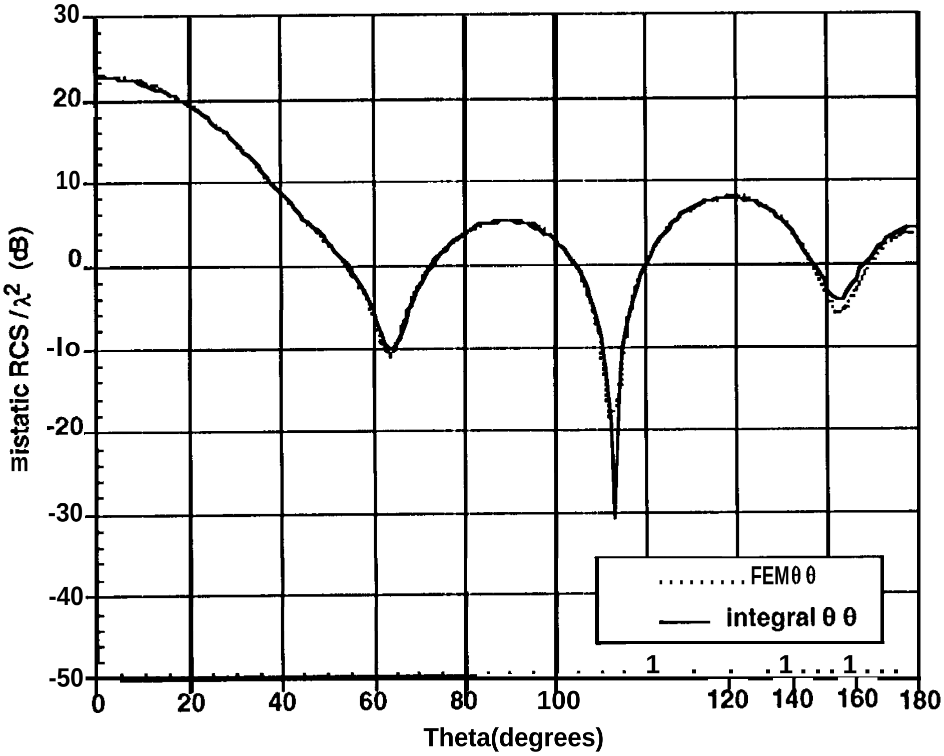

Fig. 4. Bistatic RCS of ferrite cylinder(ε_r = 14.8, μ = 0.99, κ = 0.066) with quartz(ε_r = 3.82) matching layers, f = 17.0 GHz